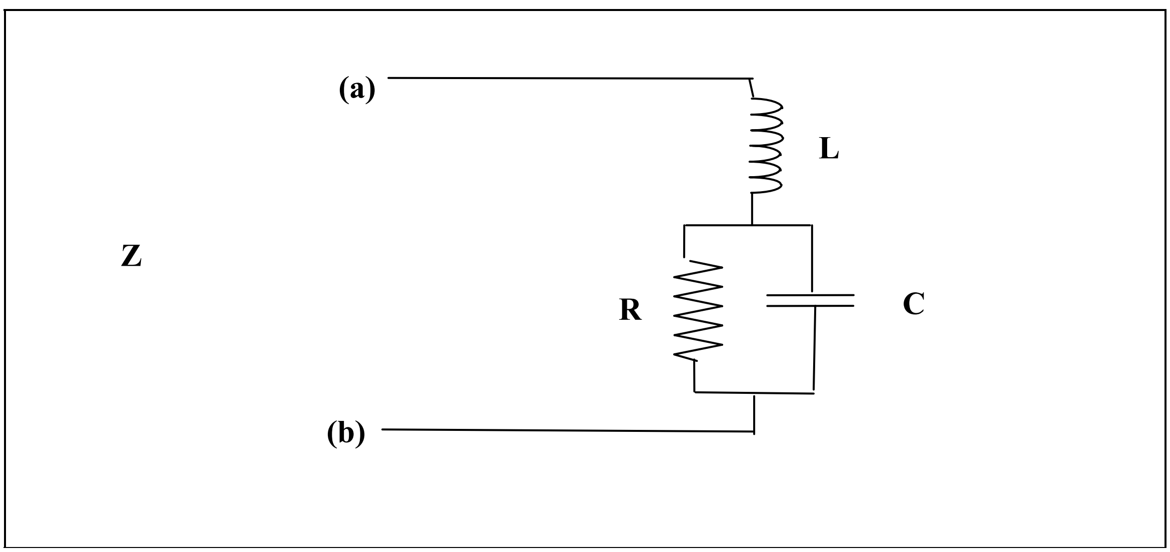
EP311 Fall Term 2004
Final Exam (50% of total course grade)

6 problems, all equal weight

Problem 1: Impedance and s-plane pole diagram

Write the impedance **Z(s)** presented between the terminals (a) and (b) of the circuit shown below. Arrange the expression for **Z(s)** such that you have polynomials in increasing powers of **s** in both the numerator and denominator. Use the formula **V = I Z** to argue why the zeros of **Z** define the free (natural) response of the current **I** when the terminals (a) and (b) are shorted.

Now consider the specific component values L = 1 H, R=5 Ohm, and C=0.1 Farad. Plot the zeros of **Z** on the imaginary plane *for the particular component values specified only*. Write the general form for the time-dependent response of the current if the terminals are shorted at time t=0.



Problem 2: Semiconductor Doping & Diode Behaviour

The portion of the periodic table most important for semiconductor work is reproduced below. Relevant physical constants are included for Silicon.

Group III	**Group IV**	**Group V**
Boron (B) Z=5	Carbon (C) Z=6	Nitrogen (N)Z=7
Aluminum (Al) Z=13	Silicon (Si) Z=14 Atomic concentration $= 5.0 \times 10^{22}$ cm^{-3} $n_i = 1.5 \times 10^{10}$ cm^{-3} $\mu_e = 1350$ cm^2/V.s $\mu_h = 480$ cm^2/V.s	Phosphorus (P) Z=15
Gallium (Ga) Z=31	Germanium (Ge) Z=32	Arsenic (As) Z=33
Indium (In) Z=49	Tin (Sn) Z=50	Antimony (Sb) Z=51

You are working in a semiconductor doping lab. A colleague asks you to investigate whether it will be possible to dope silicon to produce a conductivity equal to that of copper at 300 Kelvin. Your colleague will be happy with either p-type or n-type doping.

For both the p-type and n-type cases, pick a suitable doping atom species and calculate the atomic concentration of dopant atoms required. Feel free to use any reasonable approximations which you can justify.

Useful information: at 300 K, σ(Cu) = 5.88×10^5 Ohm^{-1}cm^{-1}
Recall $\sigma = e(n_e \mu_e + n_h \mu_h)$ {e = electron charge = 1.6×10^{-19} Coulomb}

Based on your calculations above, answer the following question:
Is it reasonable to dope silicon to a level where it has a conductivity comparable to copper ? Why or why not ?

(b) At room temp (assume 25 degrees C) a silicon diode has a reverse saturation current of 1 picoAmp. What is the current flowing in this diode at a forward bias of 0.7 Volt ? Now imagine that due to the power dissipated the diode temperature increases to 75 degrees C. What is the forward bias current at 0.7 V at this new temperature ?

Ref: Shockley equation $I = I_0 [e^{(eV/\eta kT)} - 1]$ ($\eta \approx 1$ and $k = 1.38 \times 10^{-23}$ J/K)

Problem 3: Bipolar Junction Transistor (BJT) Amplifier

(a) From the output characteristic curves for transistor Q1 given in the right-hand figure, what is the approximate value of **β**.

(b) Sketch the power dissipation hyperbola (Q1 max power = 2.5 Watt) on the transistor curves provided.

(c) From the given load line, what is the value of Rc ?

(d) Consider the standard BJT bias stability equation: $I_C = \dfrac{V_{BB} - V_{BE} + (1+\frac{1}{\beta})I_{CBO}(R_B + R_E)}{R_E + \frac{R_B + R_E}{\beta}}$

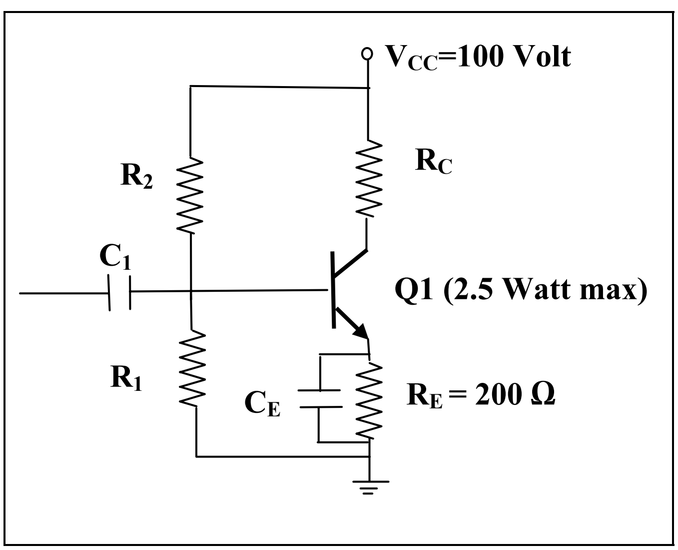
Recall R_B is the parallel combination of R_1 and R_2, i.e. $R_B = R_1 // R_2$.

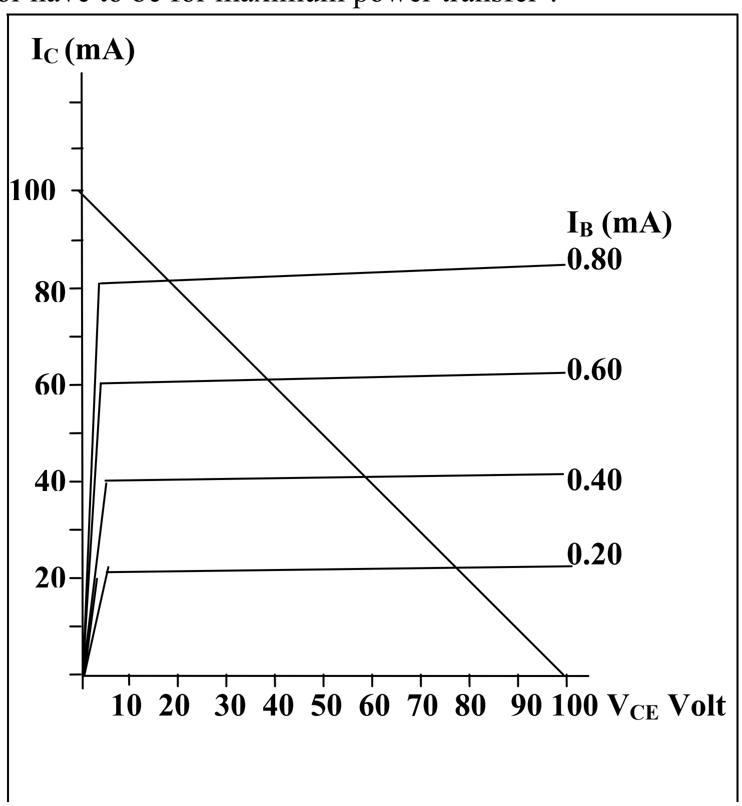
Assume the base bias current is 0.4 mA. Plot the corresponding Q-point.

Now use the above equation to design a suitable stable bias network (i.e. choose values of R_1 and R_2).

(e) If the lowest desired frequency of operation is 500 Hz, choose capacitors C_1 and C_E

(f) Without removing any parts from the circuit, sketch how we could couple out the signal to an external load resistor. What value would this resistor have to be for maximum power transfer ?





Problem 4: Enhancement MOS Field-Effect Transistor (MOSFET) Circuit

Note: for the graphing questions (a) and (b), use the graph paper included (see next page)

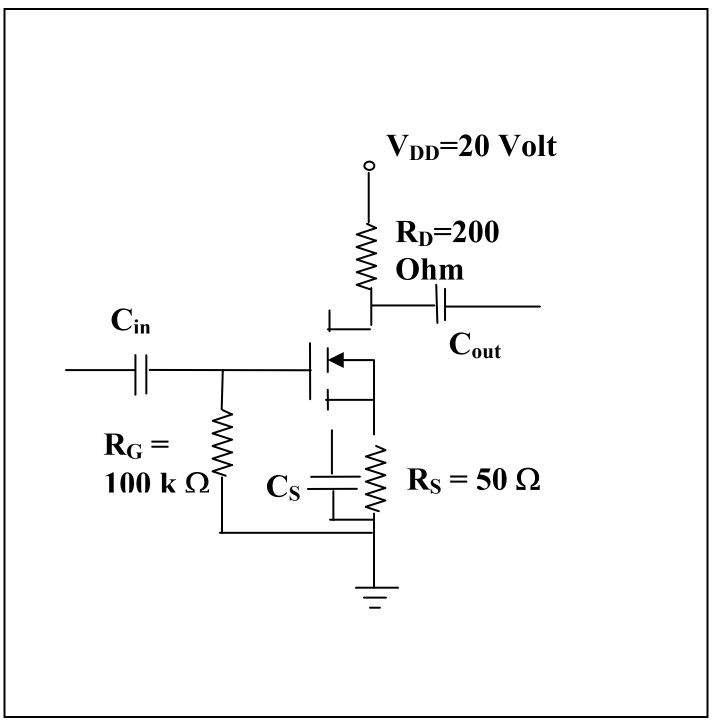
For the enhancement MOSFET circuit shown below:

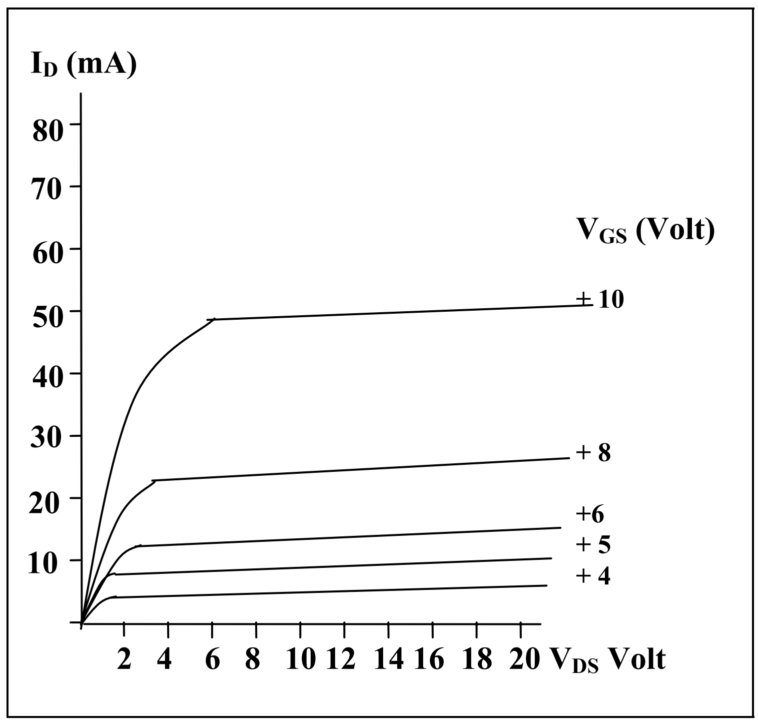
(a) For a fixed value of V_{DS} in the normal region of operation, sketch a graph of I_D vs. V_{GS}.

(b) On the same axes used in (a), sketch a plot of the standard relation $I_D = K(V_{GS} - V_T)^2$ where V_T= 2 Volt and K = 0.78 mA/Volt^2 Comment on the agreement between this curve and the data points plotted in (a).

(c) Plot the DC load line for the circuit

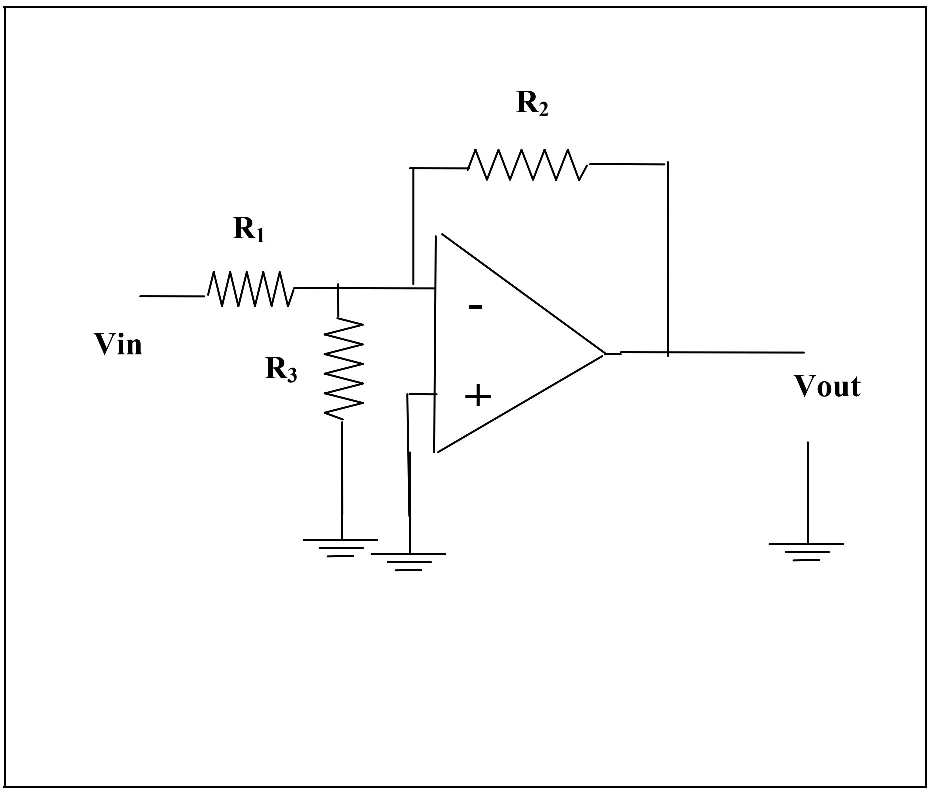
(d) If the circuit is intended for at frequencies above 100 Hz, choose a suitable value for the source bypass capacitor Cs





Problem 5: Op-amp Dc Circuit

Use the op-amp current and voltage rules (OACR and OAVR) to derive the expression relating the output voltage **Vout** to the input voltage **Vin** for the circuit below:



Problem 6: Op-amp filter circuit

Derive the transfer function $T(\omega) = Vout(\omega)/Vin(\omega)$ for the following active filter circuit as a function of frequency, using the op-amp current and voltage rules (OACR, OAVR).